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EFFECT OF ILLUMINATING GAS AND ETHYLENE UPON FLOWERING CARNATIONS

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 116

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(WITH FOUR FIGURES)

1. Historical

As early as 1864 observations were recorded on the effect of illuminating gas on vegetation. GIRARDIN (1) called attention to the phenomena of gas injury to trees as reported from various places in Rouen, Berlin, Hamburg, Hanover, etc. He especially investigated injury done to Italian poplars which had come into use as shade trees along the highways. He made a chemical analysis of samples of soil taken three feet from leaks in the gas pipes, and found inflammable oil as well as sulfur and ammonia compounds present. R. VIRCHOW (2) expressed an opinion that coal gas is especially injurious to vegetation. KNY (3) was one of the first to test the injury experimentally. He used three sound trees in the Berlin Botanical Garden, each about twenty years old—one maple and two lindens. Gas pipes were carefully laid 84^{cm} deep and the gas used was freed of sulfuretted hydrogen. The two pipes were laid in a circle about the maple, and four burners were attached at a distance of 118^{cm} from the trunk. Near each linden tree were two burners, 110^{cm} from the trunks. The gas escape was measured daily.

- | | |
|-------------------------------|-------------------|
| (1) Maple received daily..... | 12.9 cubic meters |
| (2) First linden..... | 11.7 cubic meters |
| (3) Second linden..... | 1.6 cubic meters |

The experiment was begun July 7 and lasted for (1) and (2) a half-year, for (3) a full year. First a *Euonymus* (*E. europea*) near the maple died, then the maple lost its leaves (September 1). At the same time an elm near by showed injury. September 30 the first linden showed signs of injury. On October 12 the first linden lost its leaves, and on October 19 the second, while other lindens in the garden were yet green. An examination of roots one-half inch in diameter showed a blue coloration extending out from the middle

toward the periphery. The following spring the maple, elm, and Euonymus bush showed no signs of life. The lindens produced foliage, but the leaves were bleached and smaller than usual. Dried cambium and a rich growth of fungi were further indications of injury.

Similar investigations were carried on by SPÄTH and MEYER (4). In one case during the summer a little less than $1^{\text{cu. m}}$ of gas diffused daily through $17.8^{\text{cu. m}}$ of soil in a wooded plot. The roots of all the trees were killed within a few days. During four winter months the same amount of gas was allowed to escape into a wooded plot of twice the above area. In this case Platanus, silver poplar, American walnut, and Ailanthus were killed; the maple and horse chestnut were greatly injured; while the linden showed no injury. In another experiment $0.0185^{\text{cu. m}}$ of gas was daily distributed equally among seventeen trees. The experiment lasted from April 11 to June 27. Before May 30 six of the more sensitive trees had died. By June 21 all the others, with the exception of the rough-fruited maple, had slackened their growth. The leaves of the injured trees were a pale green or yellow, and most of the younger roots were dead. According to the statement of the gas inspectors, their methods were not capable of detecting such light leaks as are shown in this experiment. These investigators found that when the surface of the soil is compact, the gas may travel long distances before reaching the surface. An instance is cited of gas traveling from a leak on one side of a street to a cellar on the opposite side, where it became evident by an unbearable smell. These investigators concluded that trees are far less sensitive to gas leaks during the winter than during the growth period. They also found much more rapid injury where the surface of the soil was packed. The small quantity of gas necessary to kill and the great distance that gas travels through the soil serve to emphasize the danger to which trees are exposed.

H. EULENBERG (5), besides summarizing the results given in previous literature, adds the birch to the list of less sensitive trees.

J. BÖHM (6) grew slips of water willow in water through which gas was passed. He found that they produced only short roots and that these soon died, as did also the buds. The twigs themselves remained alive for about three months, until, as he believes, the

reserve food had been exhausted. In another experiment he found that soil impregnated with gas was very poisonous to plants, for seeds put to germinate in it started, but their roots soon died. A *Dracaena* planted in such soil died in ten days. Far less injury was shown when a given quantity of gas was in contact with the portions of the plant above the ground than when the same quantity came in contact with the roots by being passed into the soil. The roots, he concludes, are most sensitive to gas injury. He found potted plants of *Fuchsia* and *Salvia* only moderately sensitive to illuminating gas that was allowed to bubble through the soil.

LACKNER (7) states that camelias, azalias, cacti, and ivy are much injured if kept in rooms where illuminating gas is burned; while palms, dracaenas (*Acuba japonica*), and many other plants escape uninjured. He asserts that it remains to be determined whether it is escaping portions of unburned gas or products of incomplete combustion that produce the injury.

C. WEHMER (8) calls attention to a severe case of gas poisoning in Hanover. Thirteen elm trees along a street showed injuries varying with the distance they stood from a leak in a gas pipe. In late winter a number of them showed brown discoloration of the inner bark, and a falling-off of bark in large patches extending up the trunk six feet from the ground. No blue discoloration of the roots appeared as was reported by KNY and other observers. The author asserts that the area of the injury was especially great because of the hard-packed street above the leak.

MOLISCH (9) found that illuminating gas is more injurious to the roots of plants than chlorin or carbonic acid. Growth in length is retarded by 0.005 per cent. of illuminating gas. If uninjured and decapitated roots of corn are grown in illuminating gas, the former are remarkably bent and retarded in their growth in length, while the latter grow almost straight and are comparatively vigorous. Under the influence of the gas the growth in thickness of the roots is increased, the greatest thickening occurring where the bending is sharpest. When a 10-20 per cent. mixture of illuminating gas exerts a stimulus from one side, the roots respond negatively.

NELJUBOW (10) notes some very interesting effects of illuminating gas upon the etiolated seedlings of peas and other legumes. WIESNER

had already reported a horizontal nutation of these seedlings, which he explained as autonomic. RIMMER later explained this horizontal growth as a response to unfavorable conditions, especially lack of moisture in the air. NELJUBOW found that while this response always occurred in the dark in the laboratory air, it did not occur in the dark in a greenhouse or in the outside air. After determining that temperature and moisture were not factors, he sought the explanation in impurities of the laboratory air. He found that laboratory air passed through KOH, Ba(OH)₂, CaCl₂, red hot CuO, and finally through Ba(OH)₂ gave vertical seedlings; while similar treatment with the CuO unheated gave seedlings with the horizontal placement. This proved that some impurities (probably some of the constituents of illuminating gas) of the laboratory air, which were oxidized by glowing CuO, caused this peculiar horizontal placement. He later produced the effect with mixtures of illuminating gas. He likewise tested a number of the constituents of illuminating gas. Acetylene produced this nutation, but was difficult to work with, because, on the one hand, a slight increase in concentration killed, and on the other, it rapidly disappeared because of its high solubility in water. One part of ethylene in 1,000,000 of air gave the response, while one part in 4000 killed the majority of the seedlings. He likewise mentions the fact that various other constituents (benzene, sulfur dioxide, hydrogen sulfide, and carbon bisulfide) of illuminating gas are highly toxic. He makes no attempt, however, to determine the toxic limits of the several constituents, or to learn whether one or several determine the toxic limit of illuminating gas.

SHONNARD (11) mentions several manifestations of the injury of illuminating gas to trees, and describes an experiment with a potted lemon tree exposed to a flow of 1.07^{cu.ft} of gas per hour. After eight days he notes the exudation of sap in considerable quantity from trunk and branches, as well as the discoloration and falling-off of the leaves.

RICHARDS and MACDOUGAL (12) tested the effect of carbon monoxide and illuminating gas upon various seedlings. Carbon monoxide, heretofore considered neutral, was shown to be toxic. It was not so effective as illuminating gas, however, in modifying the rate and amount of growth of root and shoot, in retarding the differ-

entiation of the primary tissue, and in hindering the formation of chlorophyll. Gametophytes of certain mosses were found to be very resistant, suffering very little injury in high concentrations of these gases for three months. A more delicate moss, presumably *Mnium undulatum*, however, showed deleterious effects earlier. In *Elodea* and *Nitella* older cells were most injured, and the injury was shown by plasmolysis of the cells. A considerable part of their experimentation with illuminating gas serves to confirm the results obtained by MOLISCH, NELJUBOW, BÖHM, and others. The conclusion that "illuminating gas affords, in addition to the action of carbon monoxid, the results of the action of other substances deleterious to plants" seems to indicate that the work of NELJUBOW and others was entirely overlooked.

STONE (13) calls attention to the fact that very small leaks ($2-3^{\text{cu. ft}}$ per day) of gas may cause local injury to trees. Among manifestations of gas-killing in trees, he notes the early appearance of an abundant growth of fungi in contrast to the relatively late appearance on other dead trees. In speaking of the distance gas may travel he says: "In gravelly soils we have known gas to travel 2000 feet without difficulty, when the ground is frozen, and escape into the cellar of a house; whereas in heavier soils gas is more likely to be restricted to smaller areas."

RICHTER (14) and other investigators have pointed out a number of effects of impurities of laboratory air upon the responses of seedlings. RICHTER believes that in a number of cases the negative geotropism of hypocotyls is greatly weakened by these impurities. He points out that a one-sided illumination will produce far more nearly a horizontal position with than without these impurities. He likewise asserts that in many species the degree of horizontality from one-sided illumination indicates the degree of impurity of the air. He found great variation, however, in sensitiveness in different species even of the same genus.

2. Scope, method, and preparation of material

It is quite commonly asserted that plants do poorly in houses lighted with gas and especially is the flowering interfered with. Various inquiries have come to us from carnation growers as to the

effect of illuminating gas upon the flowering carnation. These growers claimed to have had heavy losses from gas that seeped from defective pipes through the ground into the greenhouses. In some cases it is claimed that the losses occurred during cold weather, when little ventilation was possible and when the ground was frozen, so that upward diffusion from the defective pipes was hindered and thereby lateral diffusion fostered. In all these cases it is claimed that the injuries ceased with the repair or removal of the pipes.

Upon looking up the literature it was found that no accurate determinations were made upon the effects of illuminating gas and its constituents upon flowers, and that in no case have the toxic limits and relative toxicity of the several main constituents been determined. In short, it is not known in any case whether the toxic limit of the gas is determined by the action of one constituent or by the combined action of several. To answer these questions is the purpose of the investigation here reported.

This paper will deal entirely with the buds and flowers of the carnation, describing in detail the effects and toxic limits of illuminating gas and ethylene. A later paper will give in detail similar data for the other main constituents of illuminating gas, as well as describe the effects of illuminating gas and all its main constituents upon the vegetation of the carnation. The work naturally falls into these two divisions, for, as will be shown by experiments described later, the flowers are far more sensitive to illuminating gas than is the vegetation, and the toxic limit of the gas on the flowers seems (from all the evidence of our experiments) to be entirely determined by the ethylene it contains.

To determine the relative sensitiveness of buds and flowers on the one hand, and the vegetation on the other, as well as the relative sensitiveness of buds and flowers of different ages, one series of experiments was carried on by exposing entire potted plants to an atmosphere containing small proportions of gas. This was done by setting the plants into an air-tight greenhouse within the laboratory greenhouse, and then running desired quantities of gas into the air-tight greenhouse. This sort of experiment has some serious faults. It does not determine whether the flower is affected directly by the gas contained in the air about it, or whether the effect is indirect by

injury to the plant through the absorption of gas by the soil and later by the roots. Also no definite determination of the toxic limit of the gas can be made, for the amount absorbed by the soil is not determinable.

To avoid such sources of error the buds and flowers still intact were exposed individually to the desired concentrations of the gases. This was accomplished by the use of the apparatus shown in *fig. 1*.

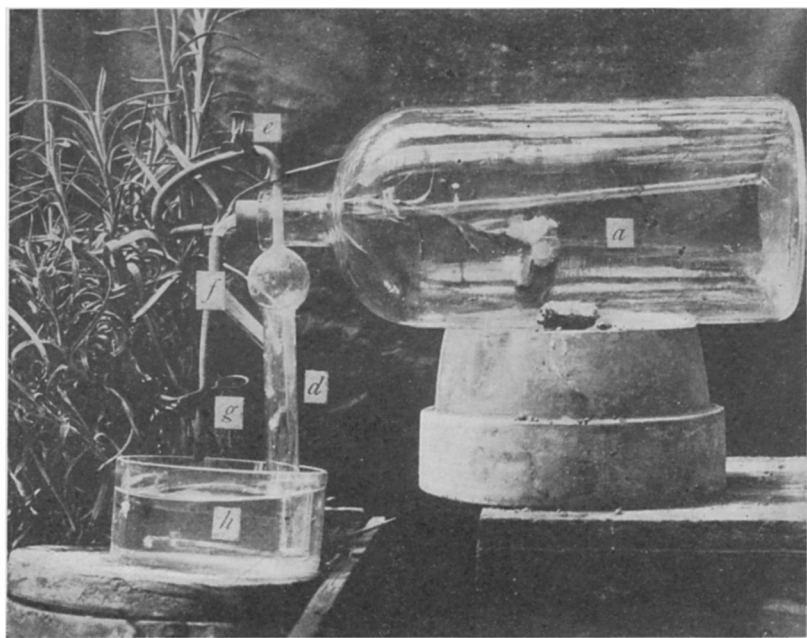


FIG. 1.—For description see text.

The bottle *a* is furnished with a three-holed rubber stopper. In one hole of the stopper is a straight glass tube reaching nearly to the bottom of the bottle. A calcium chlorid tube (*d*) is attached to the projecting end of this tube by means of a rubber tube furnished with a pinchcock (*e*). In the second hole of the stopper is a short bent glass tube (*f*), the outer end of which is furnished with a rubber tube and pinchcock (*g*). The third hole in the stopper is small and is capable of having the stem of the carnation inserted from the side by a split, which reaches from the hole to the margin of the cork. In setting

up the experiment the cork is placed on the stem of the carnation by opening the cork at the split and inserting the stem. The flower or bud and the long tube are put into the nozzle of the bottle and the cork forced in until the whole apparatus is air-tight. The free end of the calcium chlorid tube is placed into a dish (*h*) of water or (with gases highly soluble in water) mercury; both pinchcocks (*e* and *g*) are opened; and suction applied to the tube *f* until the liquid rises to the small portion of the calcium chlorid tube, at which time pinchcock *g* is closed. The desired quantity of gas which is now poured into the wide end of the calcium chlorid tube rises to the top of the liquid. A one-holed rubber stopper, furnished with a tube and attached to a column of the same liquid as is contained in the dish, is now inserted into the free end of the calcium chlorid tube (*d*), and the pressure of the column allowed to force the liquid to the inner end of the long tube. This forces the gas into the end of the bottle farthest from the flower and allows a gradual distribution by diffusion. For ethylene and illuminating gas water was always used as the forcing liquid.

In determining the toxic limits of illuminating gas and ethylene, 20-liter carboys were used; while smaller bottles were employed in some of the earlier experiments with these gases, as well as with all the determinations of the least toxic gases. The question of the effect of corking a bud or flower in a closed chamber of this kind naturally arises, and suggests a criticism upon the method. It was found that flowers opened without any apparent injury when corked in flasks of only one liter capacity. In all checks and in all cases where the concentration of the injurious gas was below the toxic limit, the flowers bloomed normally while yet in the bottles. To avoid undue rise of temperature within the chambers basket-covered carboys were used. The experiments were carried on in the laboratory greenhouse during the months of May to September. The temperature in the experiments reported varied from 20°–28°, and within this range no noticeable variation in toxicity appeared.

Two varieties of carnations were used—the Boston Market and the pink Lawson. The two varieties vary so little in their sensitiveness and reaction to ethylene and illuminating gas that a description of the responses of one applies equally well to the other.

To make sure that the effect produced by ethylene was not due to some impurity contained by it, parallel experiments were run with ethylene derived by two different methods: (1) by heating concentrated sulfuric acid with absolute alcohol, and (2) by dropping absolute alcohol upon phosphorous pentoxid heated to 200° C. and later raised to 240° C. The ethylene derived from sulfuric acid was washed by the ordinary gas burette and pipette, as described by HEMPEL (15: 34-95); first in concentrated sulfuric acid (sp. gr. 1.84) to remove the aldehyde, and later in 33 per cent. potassium hydrate to remove the sulfur dioxid. In each case the washing was continued until no further absorption occurred. The ethylene derived from phosphorous pentoxid was washed similarly, and in addition in copper sulfate (sulfuric acid solution described by HEMPEL, p. 316) for absorption of phosphene, if any should be present. Various samples of the ethylene derived in this way were analyzed. Bromin and fuming sulfuric acid absorbed 96-98 per cent. The unabsorbed portion proved to be air, coming from the generator chamber. The gases thus derived were diluted with air to form mixtures containing 2 per cent. ethylene. The toxicity of the two mixtures was equal.

In discussing the composition of illuminating gas we can hardly do better than quote a paragraph from SMITH'S (16) *General chemistry for colleges*:

The illuminating gas in Europe, and in many of the smaller cities of the United States, is usually coal gas; while in the larger cities of America it is almost always made from water gas. Coal gas is obtained by the destructive distillation of soft coal, and is freed from ammonia and tar by washing and cooling, and from hydrogen sulfid and carbon dioxid by passage through layers of slaked lime. The water gas, made by the action of steam upon anthracite or coke, being composed of carbon monoxid and hydrogen, has no illuminating power. It is therefore "carburetted," that is, mixed with hydrocarbons, by passage through a cylindrical structure filled with white-hot firebrick, upon which falls a small stream of high-boiling petroleum. The relatively involatile hydrocarbons of which the oil consists are thus decomposed ("cracked"), and gaseous substances of high illuminating power are produced. The following table shows the composition of each of these kinds of gas, together with that of oil gas (Pintsch's) which is composed entirely of the products from "cracking" oil:

Components	Coal gas	Water gas	Oil gas
Illuminants.....	5.0	16.6	45.0
Heating gases:			
Methane.....	34.5	19.8	35.8
Hydrogen.....	49.0	32.1	14.6
Carbon monoxid.....	7.2	26.1
Impurities:			
Nitrogen.....	3.2	2.4	1.1
Carbon dioxid.....	1.1	3.0
Candle power.....	17.5	25.0	65.0

These are average numbers, and considerable variations from these proportions are often met with. The illuminants are unsaturated hydrocarbons, such as ethylene and acetylene, and the value of the gas for illuminating purposes depends on the amount of these particular components.

The illuminating gas used in our experiments was water gas of the People's Gas Light and Coke Company, drawn from a tap in the Botanical Laboratory. In numerous analyses of samples of this gas (see HEMPEL, p. 282) absolute alcohol absorbed 0.2-0.6 per cent., and fuming sulfuric acid 11-14 per cent. Absolute alcohol absorbs the so-called hydrocarbon vapors (mostly benzene); and fuming sulfuric acid the heavy hydrocarbons, including acetylene, ethylene, and their higher homologues. Bromin is often used as an absorbent of ethylene. Besides ethylene, however, it absorbs several other constituents of illuminating gas. In a number of analyses this reagent absorbed 9-13 per cent. A more definite determination of ethylene will be given in the experimental portion.

At first the illuminating gas used was washed through 33 per cent. potassium hydrate to absorb any traces of sulfur dioxid and hydrogen sulfid it might contain. This was found not to modify the toxicity, and hence the unwashed gas was used thereafter. The methods of deriving and purifying the other constituents (of illuminating gas) worked with will be described in the later paper, which gives their effects.

3. Experimental

ILLUMINATING GAS

As a later paper will deal fully with the effects and toxic limits of the constituents other than ethylene, we need make only a general statement concerning them here. A number of experiments were run

to determine the toxic limits of methane, carbon monoxid, acetylene, hydrogen, carbon bisulfid, and benzene to the buds and flowers. As would be expected, hydrogen was perfectly neutral when it completely displaced the nitrogen of the air. In all the other constituents here mentioned, the toxicity was such that in the least amount of illuminating gas necessary to kill the bud no one is concentrated enough to reach $\frac{1}{60}$ of its toxic limit. It is very probable, therefore, that these constituents play no part in determining the toxic limit of illuminating gas. It has already been stated that the absorption of hydrogen sulfid and sulfur dioxid does not modify the toxicity of the gas. This leaves, then, ethylene, the higher homologues of ethylene and acetylene, and certain aromatic sulfur compounds to account for the toxicity of the gas. All these substances except ethylene exist in very small percentages in illuminating gas. All evidence in the following experiments also points to the conclusion that there is enough ethylene in the gas to account for its toxicity.

The small greenhouse in which entire potted plants were exposed to the action of gas had a capacity of 1.69^{cu.}m. In order to make comparisons easy between buds of the same size on the plants exposed and on the checks, corresponding buds were tagged with the same numbers. We need describe only one of these experiments. Potted plants of the Boston Market were put into the small greenhouse in the evening and 2 liters of gas were run in at the end opposite the plants, allowing a gradual distribution by diffusion. The plants were taken out the next morning to prevent injury by high temperature. The following evening the plants were returned to the enclosure and left for 60 hours (the following two days being cloudy). At the time they were put in, 4 liters of gas were run in, and the same amount was added 48 hours later, there being at that time no perceptible smell of gas in the chamber. This experiment served to show (1) that the vegetation is far less sensitive to gas injury than the buds, for there was no apparent injury to the vegetation; (2) plants remained vigorous, put out new buds, and later produced other flowers. The oldest buds (those showing color and just ready to open) and the youngest buds (those less than 0.6^{cm} in diameter) were the ones most injured. Many of the medium-sized buds, however, escaped death, although retarded considerably in their growth. The older buds

showed a slight growth of the petals, but never opened. Later they shriveled and turned yellow.

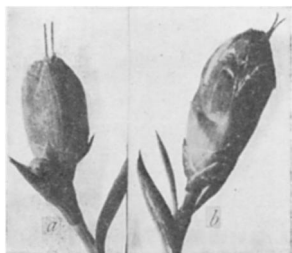


FIG. 2.—*a*, result of treating a bud, just beginning to show the petals, for three days with 1 part of illuminating gas in 20,000; *b*, result of the treatment of a similar bud, for the same length of time, with 1 part of ethylene in 500,000.

Our experiments in which individual buds were enclosed and exposed to illuminating gas began with liter flasks in which as much as 25^{cc} of gas was used. The time of exposure was usually three days, starting when the petals were just beginning to show. A gradual reduction of the concentration by reducing the amount of gas used and by increasing the size of the enclosure finally located the toxic limit. The highest concentration did no apparent injury to the vegetation; but the effect upon the buds was made apparent by a failure to open, by a discoloration and withering of the petals, and by the projection of the stigmas. When using 1^{cc} of illuminating gas to 20,000^{cc}, the stigmas still project as shown in *fig. 2, a*; 0.5^{cc} of illuminating gas did not sufficiently retard the growth of the petals to cause projection of the stigmas, yet the buds never opened farther than shown in *fig. 3*, although the petals remained fresh for several days. Very young buds were also exposed to the last concentration of the gas (1 part in 40,000, or 0.0025 per cent.) for a period of three days. The injury was not apparent at first, and the buds remained green for several days, but finally turned brown and withered.

A series of exposures was also made on the open flowers. We selected for this work those that had just opened, in order to be sure that any change produced was due to the toxicity of the gas rather than to the natural death of the flower. Here as well as in all the other experiments checks were kept. *Fig. 4, a* shows a flower before being corked in a 20-liter carboy; *b*, the same after being



FIG. 3.—Result of treating a bud, just beginning to show the petals, for three days with 1 part of ethylene in 1,000,000.

corked in a 20-liter carboy (containing air only) for 24 hours; *c*, a flower before being corked in a 20-liter carboy; and *d*, the same after being corked in 12 hours with 0.5^{cc} of illuminating gas. This shows that 0.5^{cc} of illuminating gas per 20,000 (1 part in 40,000) causes the complete closing of the flower in 12 hours or less. Higher concentrations caused a more rapid closing and a marked inrolling of the petals. With 0.5^{cc} per 20,000 and less the inrolling is not conspicuous. Even 0.2^{cc} per 20,000 causes considerable closing in 12 hours, though not as marked as 0.5^{cc}.

The effect of duration of exposure was also tested. No injury was done to a bud just ready to open upon one day's exposure to 2^{cc}

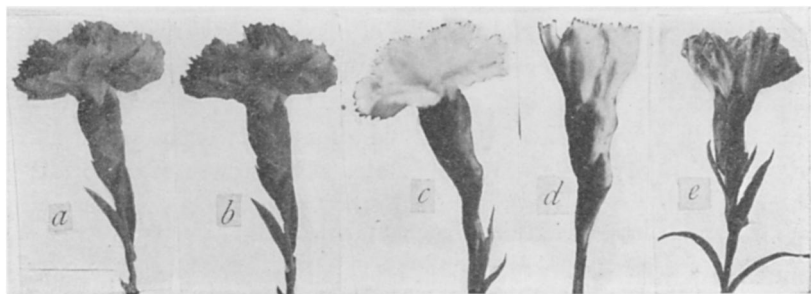


FIG. 4.—*a*, a flower that has just opened; *b*, the same after being corked in a 20-liter flask of air for 24 hours; *c*, a flower that has just opened; *d*, the same after being exposed 12 hours to 1 part of illuminating gas in 40,000; *e*, result of treating a flower that just opened for 12 hours with 1 part of ethylene in 2,000,000.

of gas per 20,000 (four times killing concentration for three days' exposure). On a similar bud 5^{cc} for one day was considerably more injurious than 0.5^{cc} for three days. The stigmas did not project, but the petals were markedly discolored.

During the entire period of experimentation there was no very marked variation in the toxicity of the gas used.¹

¹ In determining the toxic limits we located a concentration that produced the effect while one-half that concentration did not. It is clear that this permits considerable variation without detection. It is not possible to locate the toxic limits more closely, due to the variation in the flowers. It is clear, however, that this gives a very good idea of the magnitude of toxicity.

ETHYLENE

The experiments with ethylene were begun by exposing buds just beginning to show the petals to 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{16}$ cc of ethylene in 20 liters.

In each of these concentrations the buds were killed on three days' exposure. The usual signs of gas poisoning were noted; petals turned yellow and withered, and the stigmas projected. Since it was evident that these concentrations were far above the toxic limit, we resorted to the use of a 2 per cent. mixture of ethylene with air. Various amounts of this were used, until the toxic limits were definitely located. With 2 cc of this 2 per cent. mixture in 20,000 (1 part in 500,000), the results were similar to that obtaining with 1 cc of gas per 20,000 (1 part in 20,000). In *fig. 2, b* is a bud just showing the petals exposed to this concentration of ethylene for three days. Also 1 cc of 2 per cent. ethylene per 20,000 (1 part in 1,000,000) gives results similar to that shown by 0.5 cc of illuminating gas per 20,000 (1 part in 40,000). *Fig. 3* shows the results of such an exposure for three days on a bud just showing the petals. The growth of the petals is not sufficiently retarded to make the stigmas conspicuous; the petals remain fresh for several days but never open farther. Where much less than 1 cc of 2 per cent. ethylene per 20,000 was used with similar buds, three days' exposure did not prevent their opening.

When open flowers were exposed to the ethylene, it was found that 0.5 cc of the 2 per cent. mixture in 20,000 (i e., 1 part in 2,000,000) caused the closing within twelve hours. The result of such an experiment is shown in *fig. 4, e*.

It is seen from the data given above that ethylene must form approximately 4 per cent. of illuminating gas to be the constituent that determines the toxicity of the latter. It becomes necessary now to get an estimate of the fraction of the illuminating gas used that is ethylene. We have already stated that no absorbent used in gas analysis absorbs ethylene alone. In a special absorption chamber, packed in ice, 50 or more grams of bromin with 150 cc of water were placed, and measured quantities of illuminating gas passed through. When the bromin water was partially discolored, showing an almost complete exhaustion of the bromin, the resulting oil (a mixture of ethylene dibromid and other compounds resulting from the reaction

of the gas constituents with bromin) was separated, washed with a weak solution of potassium hydrate, and later with distilled water. This oil was then dried with fused calcium chlorid and later fractionated. In the first distillation all the portion boiling between 129° and 134° C. was saved. This was later redistilled and the fraction boiling between 103° and 132° C. saved as representing the ethylene dibromid, since this compound boils at 131° C. About 3 per cent. of the dried material absorbed by bromin boiled between 130° and 132° C.; a small portion boiled at 129° C. or below. From this it rose up quickly to 131° C., where it again gave a considerable fraction. Then it rose rapidly to 139° C., where a considerable fraction distilled. In one trial, 208 liters of gas at 27° C. and under pressure of 745.5^{mm} of mercury gave 130^{gm} of dried oil; of this 44.2^{gm} boiled between 130° and 132° C. After correcting for pressure and temperature the following equation equals the percentage volume of gas that is ethylene:

$$\frac{22.4 \times 760 \times 44.2 \times 300}{208 \times 745.5 \times 178 \times 273} = 2.9 + \text{per cent.}$$

In a second determination 138 liters of gas at 27° C. and 745.5^{mm} pressure gave 31.6^{gm} of oil boiling between 130° and 132° . Correcting for temperature and pressure, the following equation gives the percentage volume of ethylene in this case:

$$\frac{22.4 \times 760 \times 31.6 \times 300}{138 \times 745.4 \times 178 \times 273} = 3.2 \text{ per cent.}$$

It must be stated, however, that according to WINKLER (17) the absorption of ethylene by bromin is not complete, and farther that considerable ethylene dibromid is necessarily lost in washing, drying, and distilling, so that the percentage is probably considerably higher than here obtained. It must be urged also that the presence of other oils with boiling points rather near that of the ethylene bromid tends to make this fractionation less accurate.

4. General

It is of great interest to know that the most delicate chemical test for illuminating gas in the atmosphere falls far short of detecting amounts that work havoc with the flowers of the carnation. The tests for carbon monoxid are those used for detecting illuminating

gas. The most delicate application of the blood test (see HEMPEL, p. 225) will detect 1 part of carbon monoxid per 40,000. The iodine pentoxid test (see HEMPEL, p. 226) is of equal delicacy. If carbon monoxid forms 25 per cent. of illuminating gas, these tests will detect 1 part of illuminating gas in 10,000. Upon three days' exposure 1 part of illuminating gas in 40,000 kills the young buds and the petals of the flowers just beginning to open; while 1 part in 80,000 causes open flowers to close upon an exposure of twelve hours.

The so-called "sleep" or closing of the carnation is a source of considerable loss to growers and dealers, for flowers that once close never again open. This "sleep" is especially likely to occur with cut flowers brought into city markets. Some varieties are so disposed to react in this way that their cultivation has almost entirely ceased. We know several homes lighted with gas where cut carnations can be kept only a few hours without "going to sleep." In one instance the displacement of gas lights by electric lights entirely overcame this difficulty. Our experiments show clearly that one cause of this sleep is traces of illuminating gas (ethylene) in the surrounding atmosphere.

STONE (13), WEHMER (8), and others have shown that illuminating gas diffuses great distances through the soil, especially if there is a hard-packed or frozen crust over the top. This paper shows the extreme sensitiveness of the carnation to this substance. From these facts it is evident that carnation growers whose greenhouses are in the region of gas pipes must take great precautions against losses from this source. It would be interesting to know whether solid cement walls set into the ground for some depth on the side next the pipes would furnish sufficient protection against leaks of this kind. It is clear that, if (as our results seem to indicate) the group of illuminants, or more accurately if one constituent of this group (ethylene) determines the toxicity of illuminating gas, coal gas is considerably less toxic than water gas, while oil gas is more toxic than either of the others; also the toxicity reported by the German investigators who used coal gas is less than that shown by the gas of the great American cities.

While it seems probable that the limit of toxicity of illuminating gas on the flower of the carnation is determined by the ethylene it

contains, it does not follow that such is the case with all parts of plants or even with the flowers of all plants. It would be interesting to know the effects and toxic limits of illuminating gas and its constituents upon various double as well as single flowers. Similar data for the foliage of various plants such as *Coleus*, which is supposed to be especially sensitive to illuminating gas, would likewise be of interest.

5. Summary

1. The flowers of the carnation are extremely sensitive to traces of illuminating gas in the air.

2. With the Boston Market and pink Lawson three days' exposure to 1 part in 40,000 kills the young buds and prevents the opening of those already showing the petals. The buds of medium age are considerably more resistant.

3. In the same varieties 1 part in 80,000 causes the closing of the open flowers upon twelve hours' exposure.

4. This injury takes place directly on the bud or flower exposed and not indirectly through absorption by the roots.

5. No chemical test is delicate enough to detect the least trace of illuminating gas that will cause serious injury to carnations.

6. The "sleep" of the carnation is probably often caused by traces of illuminating gas in the air.

7. Ethylene is even more fatal to the flowers of the carnation.

8. Three days' exposure to 1 part in 1,000,000 prevents the opening of buds just showing the petals.

9. Twelve hours' exposure to 1 part in 2,000,000 causes the closing of flowers already open.

10. There is much evidence that indicates that the toxic limit of illuminating gas upon these flowers is determined by the ethylene it contains.

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